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SAI-78-567-WA NL

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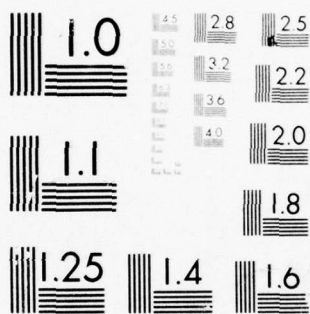
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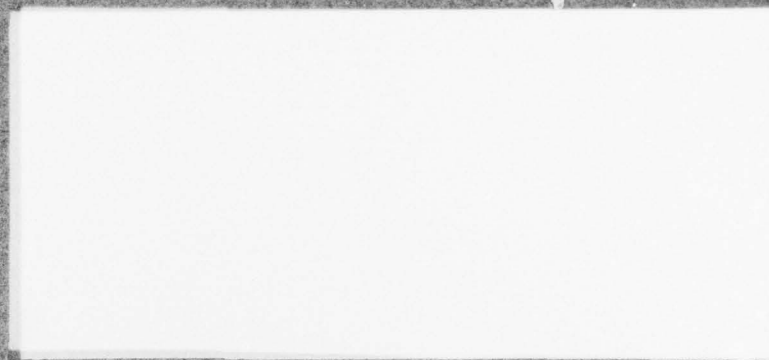
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CAPABILITY FOR THE PREDICTION OF  
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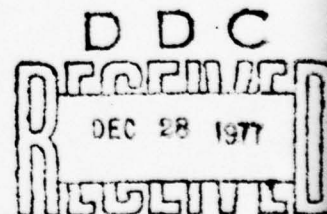
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## Section 1 INTRODUCTION

### 1.1 EXECUTIVE SUMMARY

This report documents the results of a study whose objective was to formulate a unified state-of-the-art propagation-loss model capable of handling steep as well as shallow-angle paths in a range-dependent environment. The approach which has been developed would combine the parabolic-equation (PE) results for non bottom-interacting paths with ray results (from FACT or the Multiple-Profile Program--MPP) for bottom-reflected paths. This marriage would capitalize on the accuracy of PE for the RR and RSR paths where diffraction effects limit the ray models, while using the ray formulation for the higher-angle paths where diffraction is not dominant and the ray approach is more appropriate.

### 1.2 APPROACH

This section outlines the basic approach recommended for accomplishing the program integration. The two basic issues involved in integrating the existing codes are:

- How are the physical aspects of propagation as represented by the two methods to be combined?

- How are the existing programs to be modified and supplemented with additional codes to account for the unified physical treatment and to facilitate information transfer among the codes?

Secondary issues regarding decreased running time are also addressed.

The existing set of numerical codes consists of the following:

- PE - Parabolic equation methodology is used together with a split-step Fourier Transform to "march" a solution out in range;
- FACT - This modified ray tracing code is used for range independent environments;
- MPP - The Multiple Profile Program is a ray-tracing code which is well-suited for range-dependent bathymetry and sound-speed profiles.
- CFIELD - this code interpolates the input sound-speed profile information for use in PE and MPP.

There are actually several versions of the above codes in current use. These versions represent the same methodology but are configured toward the needs of particular users. It is understood that slightly different modifications may be required for each version. However, most of the following discussion and recommendations apply to all versions. Any modifications which are strongly version-dependent will be identified.



The desired unified capability consists of the union of PE and CFIELD with either FACT or MPP. While FACT and MPP could be combined into a single program using program "flags" to indicate the desired routine, such a procedure would require excessive computer core and impair the ability to upgrade separate programs. The PE-MPP combination is appropriate for treating range-dependent environments and the PE-FACT combination applies to range-independent environments. The user, then, can select the appropriate pair in the Job Control Language (JCL) at time of execution.

The union of these programs requires some minor modifications and additions to the existing set of codes. The approach to implementing the required modifications is oriented toward the least perturbation of the existing program set. This is achieved in each case by choosing one of the following types of modifications:

- Structure of the JCL
- Addition of separate programs to the existing set
- Change of file names and I/O structure of existing programs
- Addition or modification of parameter "flags" in existing programs
- Alteration of executable code of existing programs.

The above options are listed in order of increasing impact on the existing program set. The use of the last listed option is an extreme measure and appears to be required in only a few instances, mainly concerning MPP.



The remainder of this report consists of the following:

- Section 2 discusses the physical issues involved in combining the existing program capabilities. Methods for implementing the required changes are described.
- Section 3 describes the unified program structure for the advanced capability. The required modifications involving inter-program information transfer are identified and recommendations for their implementation are made.

## Section 2

### THE PHYSICAL ISSUES

#### 2.1 INTRODUCTION

This section consists of discussions of the physical issues involved in combining PE and FACT or MPP results to achieve the unified capability. The first subsection addresses the problem background and outlines the key issues and general approach to a solution. The details of both the issues and their resolution are described in later subsections.

#### 2.2 AN OVERVIEW

The PE code obtains the pressure field by numerically solving a parabolic wave equation, which was obtained from the elliptic wave equation by the application of a set of assumptions, collectively called the parabolic approximation. The PE calculation, then, is a complete wave solution (within the limits of approximations) and includes all diffraction effects in an automatic way. The parabolic approximation limits the steepest propagation angles which can be accurately treated to roughly 20 degrees--sufficient to include most waterborne paths, but inadequate for bottom-bounce paths.

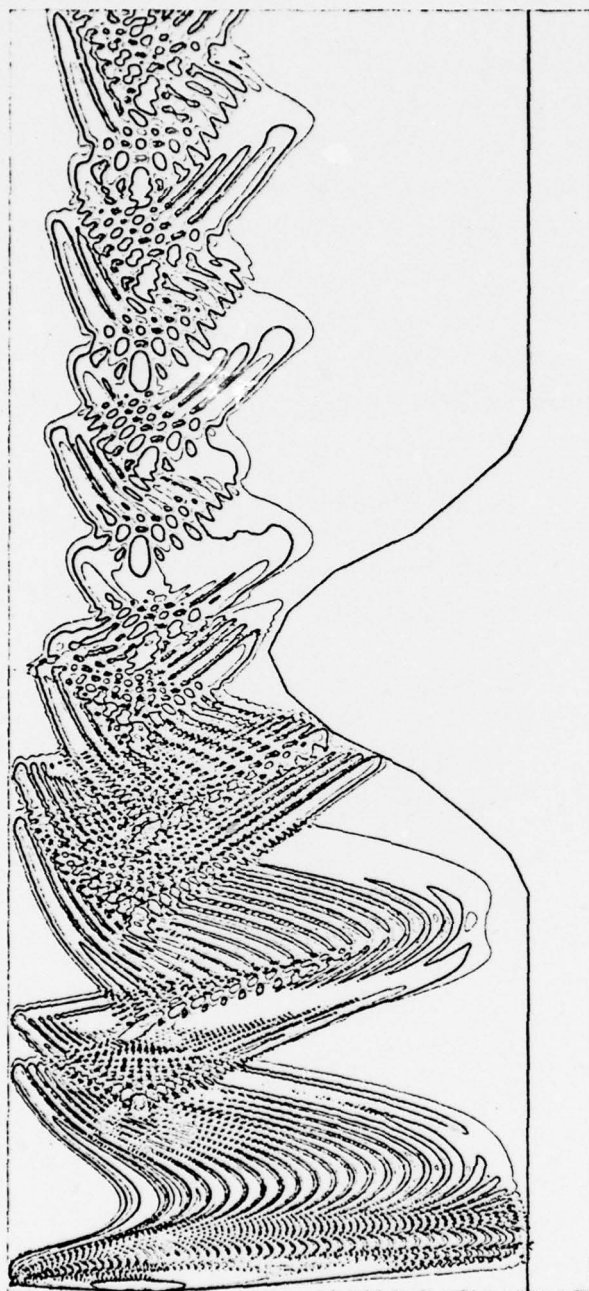
While PE generates its solution by numerically integrating the parabolic wave equation on a mesh, an alternative formulation for the same solution is in terms of the acoustic rays. The major difficulty with ray-tracing

models is their inability to treat low-frequency diffraction effects. FACT contains the most complete ray treatment of diffraction for range-independent environments, however, it still has a number of limitations. MPP, as originally formulated, attempted to extend the FACT methodology to range-dependent environments but with considerably less success. A subsequent reformulation in a "ray-sweepout" mode has overcome many of MPP's problems but is still less than adequate as a stand-alone model.

Nevertheless, the equivalence in principle between the wave and ray representations permits the formulation of an effective combined model. In a fully range-dependent environment PE would be used with a high-loss bottom which effectively absorbs all bottom-interacting paths. MPP would be used for the same sound-speed and bathymetry environment but with the appropriate bottom reflectivity. A fan of rays from nearly straight up to nearly straight down would be traced (including shallow-angle rays whose field is included in the PE results). An MPP field would be generated by adding the intensities of only those rays which have bottom reflected.

Figure 1 illustrates the iso-loss contours of the PE field generated for a typical profile with a seamount which interferes substantially with the refracted paths. Figure 2 illustrates that interference in terms of the PE-equivalent rays.

Figure 3 illustrates three (of many) rays which MPP would trace. The field from Ray 1 would not be included in the MPP field at any of the ranges shown since



DEPTH

RANGE

Figure 1. Iso-Loss PE Contours



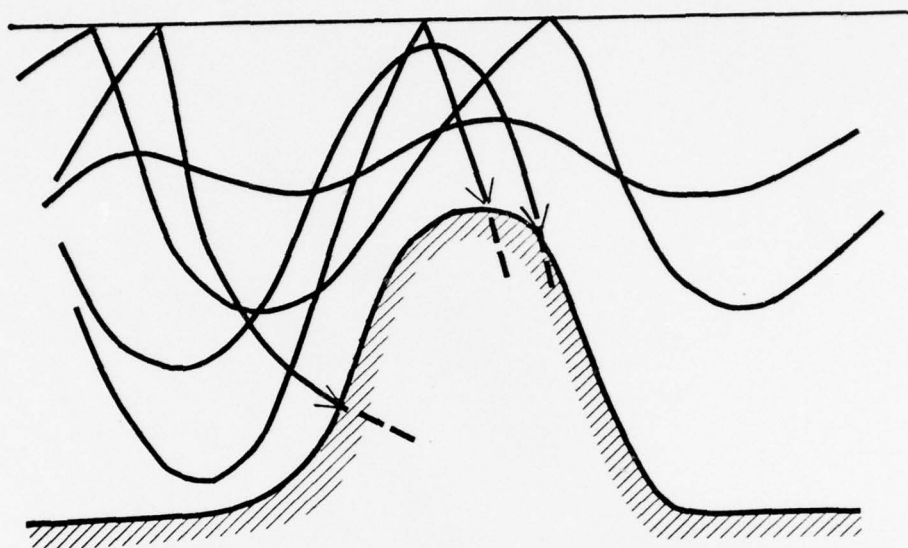


Figure 2. Effect of the Seamount on PE-Equivalent Rays



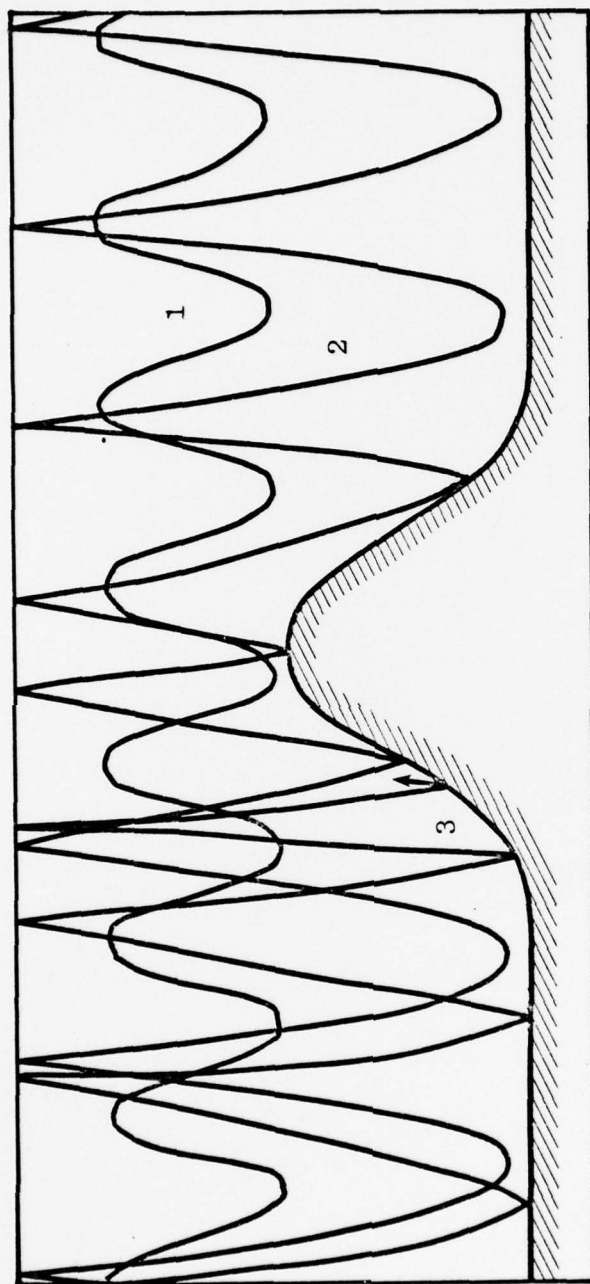


Figure 3. Sample MPP Rays

the ray never reflects off the bottom. Ray 2 would make no contribution until after its first reflection off the seamount, at which point the PE-equivalent ray is absorbed. After suffering the appropriate losses upon each of three reflections the ray converts back to RSR and may propagate to long range with relatively low loss. Even though the ray is no longer bottom-reflecting the MPP field from it could be used since it has been removed once and for all from the PE field. Finally, Ray 3 would be added to the MPP field after its first reflection and perhaps eliminated entirely after accumulating sufficiently high losses.

For range-independent environments the treatment is much simpler since the important ray families can be identified by Snell's Law and are not altered in range. Hence only the bottom-reflecting families are traced and the shallower angle rays are never required in FACT.

The above discussion has skipped one additional consideration which has its primary impact in the direct-path region. PE starts its wave solution with a Gaussian pressure solution centered about the source (or receiver) depth at zero range. For shallow angles in the far field this source appears as an isotropic (point-source) radiator. At steeper angles the source power output is considerably less, hence a compensating portion of the ray field must be added even before these steep rays have reflected from the bottom.

The PE-equivalent rays are shown in Figure 4 with the corresponding far-field radiation pattern in Figure 5a. The 3-dB down points are indicated at the angle  $\theta_0$ ,

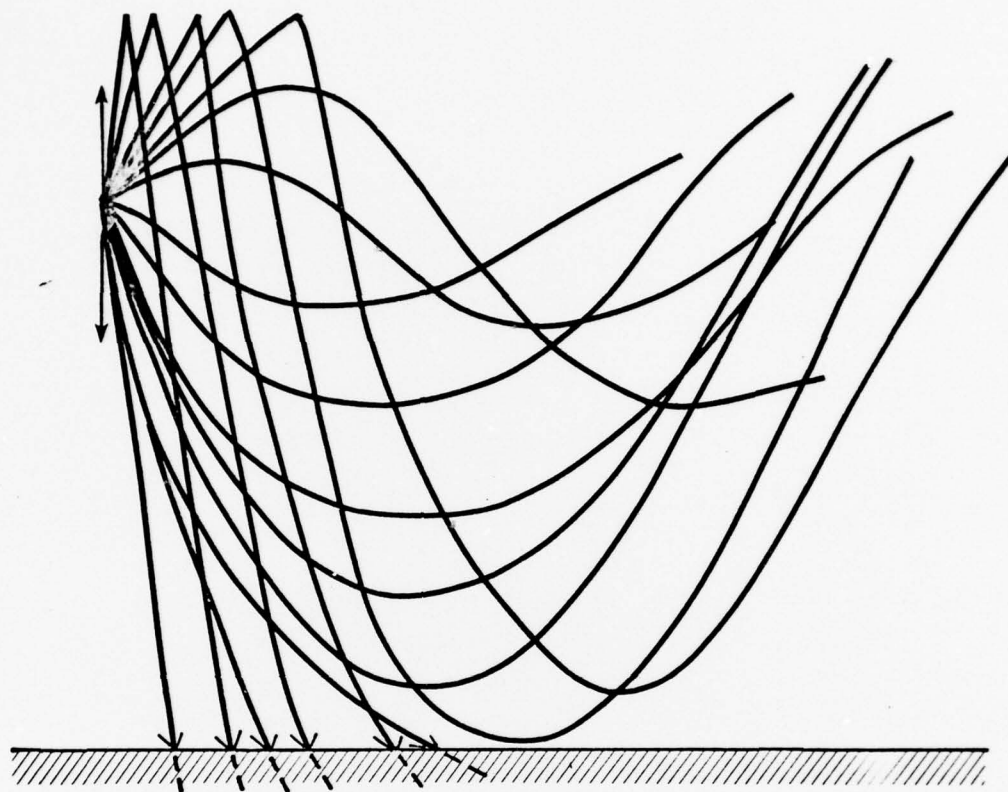
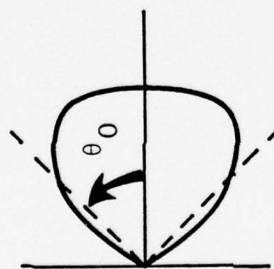
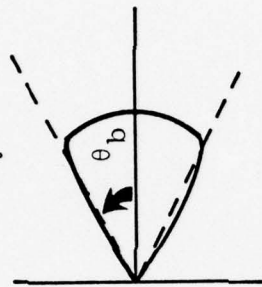


Figure 4. PE-Equivalent Rays in the Direct-Path Region



(a) Source



(b) Intermediate  
Range

Figure 5. Normalized Angular Dependence of PE Field with Highly Absorbing Bottom

which in the current PE is approximately 35 degrees. After these rays have interacted with the bottom, the effective far-field pattern is characterized in Figure 5b as being isotropic between the up- and down-going bottom-grazing rays ( $\pm\theta_b$ ). This suggests that the source was probably wider, or more isotropic than necessary to adequately illuminate the important long-range paths. This observation has important consequences for program running time and efficiency as discussed subsequently.

In summary, the combined model will compute the field at a given range-depth point by incoherently adding the PE produced intensity to the intensity of those rays crossing the point which have experienced at least one bottom interaction at a shorter range. The direct-path angle rays contributing a portion of their intensity prior to their first bottom reflection, to compensate for the PE field still present in these directions. The following subsections describe the detailed treatment of the source region, the FACT implementation, and the MPP issues, respectively.

### 2.3 THE SOURCE REGION

As stated before, the PE source is not an isotropic radiator. Specifically, the field is started by a Gaussian pressure distribution of the following form:

$$P(0,Z) = S e^{-(Z-Z_0)^2/W^2}$$



where  $Z$  is depth,  $Z_0$  the PE source (usually the acoustic receiver) depth and  $W$  the width of the Gaussian.  $S$  is chosen to normalize the source to an effective unit intensity at unit distance in the horizontal. The ratio of the parabolic-source to point-source intensities in the far field (Figure 6) is then

$$\beta(\theta) = \frac{I_{PE}}{I_{PT}} = \frac{e^{-\alpha^2 \tan^2(\theta/2)}}{\cos^2 \theta}$$

where

$$\alpha = k_0 \cdot W = \frac{2\pi f W}{c_0}$$

$f$  being the acoustic frequency and  $c_0$  the sound speed at the source. Since the PE solution will be carrying this effective source pattern along all rays prior to the first bottom interaction, the traced rays must have intensities reduced by  $\beta$  (i.e., their intensities should be reduced to  $(1 - \beta(\theta))$  times their computed values) to compensate for the PE field.

Additionally, since the PE FFT mesh spacing will be proportional to  $W$ , it is desirable to make  $W$  as large as possible to reduce running time. This is accomplished by selecting a tolerable "error" (or departure from unit intensity) for the PE field on the highest RR or RSR paths, and selecting  $W$  to produce that amount of degradation. Specifically, if an intensity departure of  $\epsilon$  is permissible at angle  $\theta_0$ , then  $W$  (and hence  $\alpha$ ) should be chosen such that

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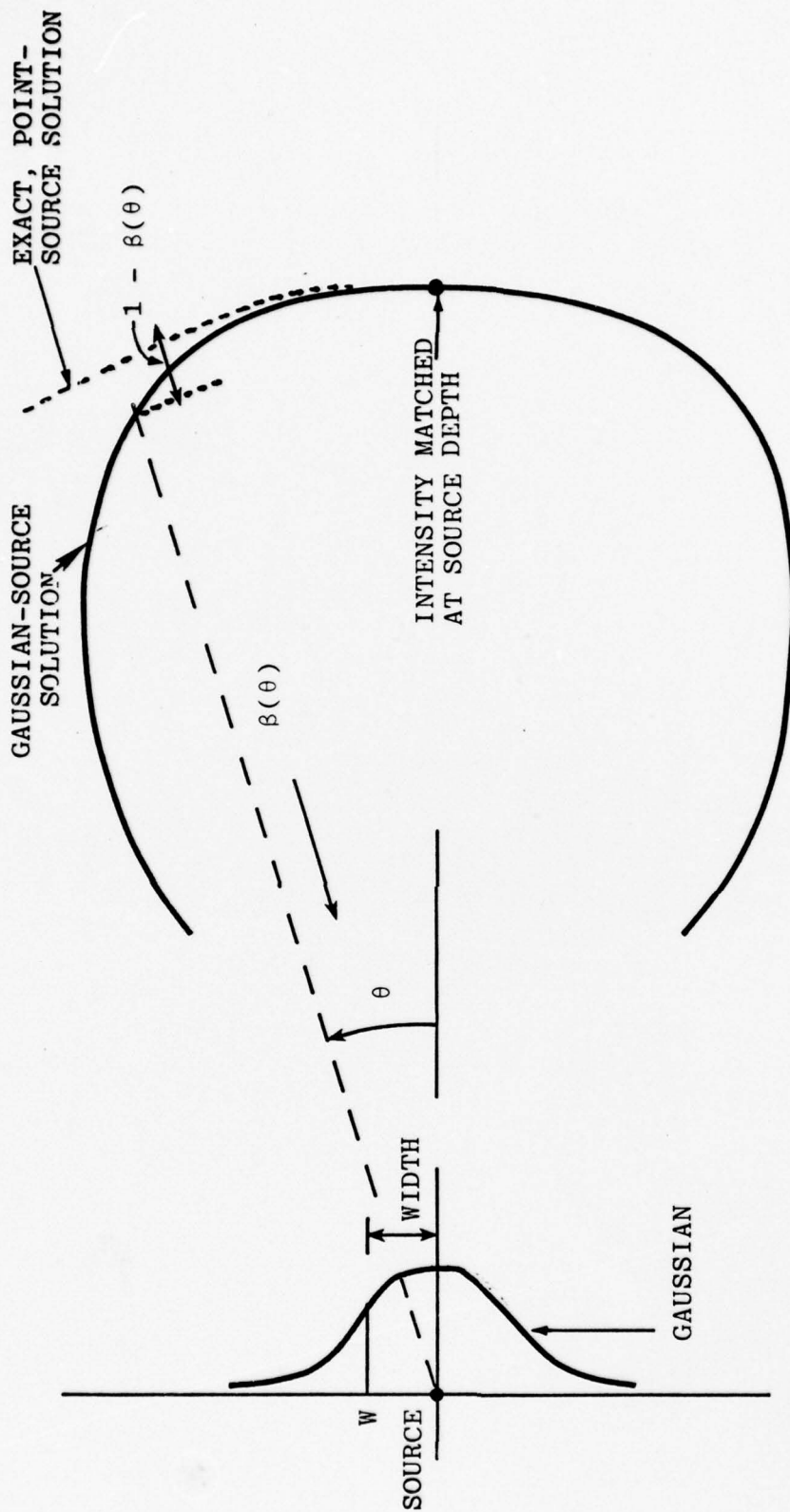


Figure 6. Gaussian-Source Depth Function and Far-Field Radiation Pattern

$$1 - \epsilon = \frac{e^{-\alpha^2 \tan^2 (\theta_0/2)}}{\cos^2 \theta_0}$$

which leads to

$$\alpha = \left\{ \frac{-2}{\tan^2 (\theta_0)} \ln [\cos^2 \theta_0 (1 - \epsilon)] \right\}^{1/2}$$

Since  $\theta_0$  is typically small  $\alpha$  may frequently be approximated by

$$\alpha(\theta, \epsilon) \simeq \sqrt{1 + \frac{2\epsilon}{\theta_0^2}}$$

Figure 7 displays the dependence of  $\alpha$  on  $\theta_0$  for permissible errors of 0.1, 0.5, 1.0, 1.5, and 2.0 dB at  $\theta_0$ . Currently in PE two options are available: a default condition of  $\alpha = 2$ , and an angle ( $\theta_0$ ) controlled value

$$\alpha(\theta_0) = \frac{\sqrt{\ln 4}}{\tan \theta}$$

The effective curves for these options also plotted in Figure 7, indicating the corresponding error as a function of angle.

In the actual implementation, the direct-path intensities of rays at angles less than  $\theta_0$  will not be included, and they will be reduced by the factor  $1 - \beta(\theta, \alpha)$



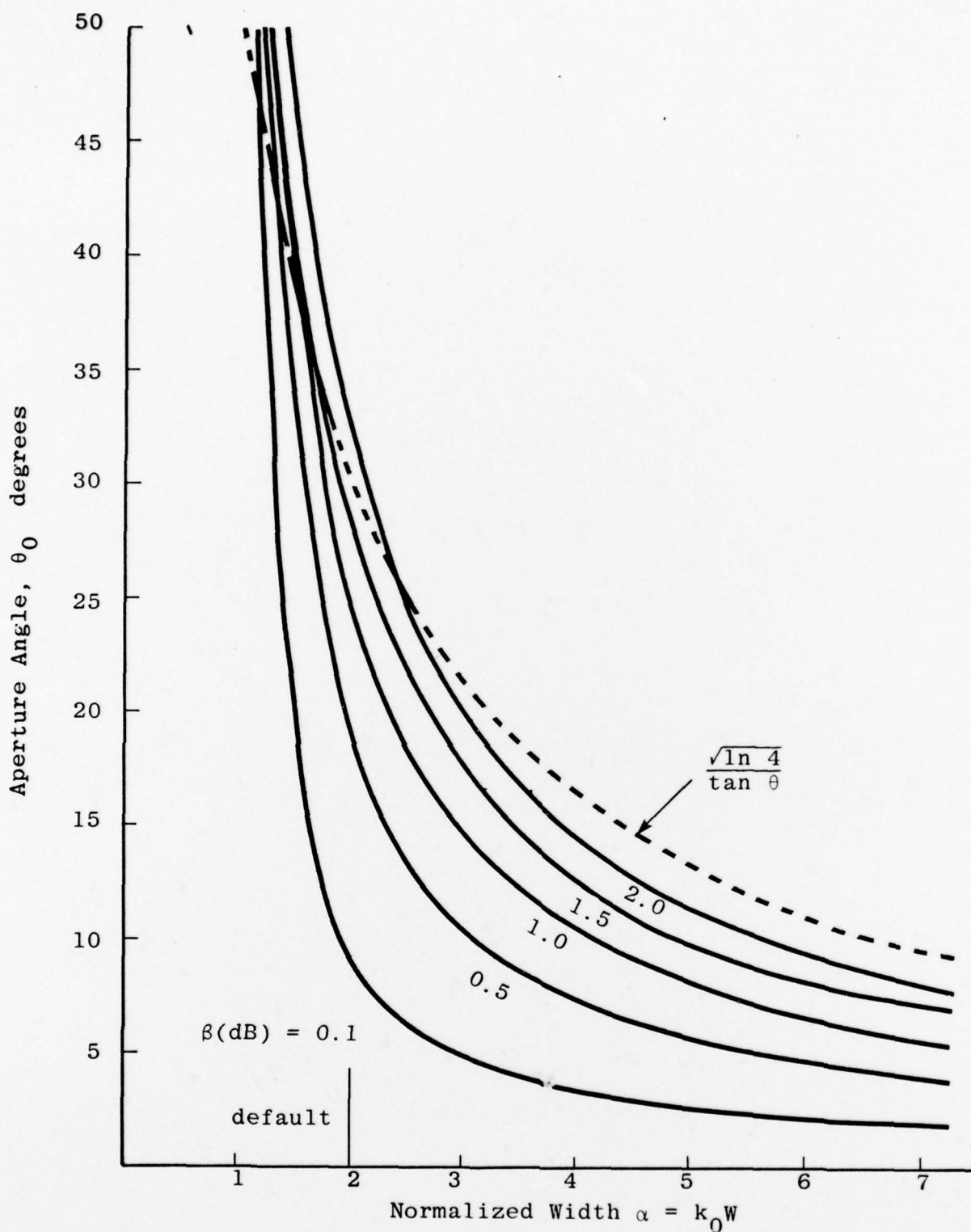


Figure 7. Dependence of  $\theta_0$  on Normalized Width,  $\alpha$ , for Selected Error Values



for angles steeper than  $\theta_0$ . Once they have bottom-reflected their entire intensity will be used. The user will have optional control over  $\epsilon$  and  $\theta_0$  with default conditions of  $\epsilon = 1$  dB and  $\theta_0$  chosen by Snell's law to be the steepest possible RR/RSR ray in the first 50 miles.

#### 2.4 FACT TREATMENT

The FACT modifications are the easiest since the environment is range-independent and the program is structured to determine the key ray families (RR, RSR, SRBR, etc.) and process their intensities separately. The first bottom-reflected ray is obtained automatically and all ray families with shallower angles will be omitted entirely.

The direct path is then processed separately and in this region the ray contributions will be multiplied by the factor  $1 - \beta(\theta)$ . Subsequent arrival orders are computed separately where the entire ray intensity will be used.

If the user wishes to compute the field at a number of depths, or contoured in depth, FACT will be executed for a sampling in depth adequate for interpolation. FACT's multiple frequency capability will be used when appropriate. More details on data storage and flow are contained in Section 3.

## 2.5 MPP ISSUES

MPP operates quite differently from FACT since, rather than treating ray families, it traces a select fan of rays, computing reflection and spreading losses along them as appropriate. In the ray sweepout mode each ray is taken to be representative of a bundle and the bundle's contribution is accumulated at the various range-depth mesh points that it covers in its trajectory. The width of the bundle is determined from the geometric spreading, limited by a diffraction expression which is frequency dependent. The bundle is also smeared somewhat in depth (as a Gaussian) to eliminate edge effects from bundle to bundle.

A present limitation of MPP in the ray sweepout mode is that the diffraction correction has not been fully tested. This should not have a significant impact on the combined capability since the rays will generally not be diffraction limited. For those which become focused after reflection from a seamount into an RR or RSR mode of propagation, reasonable limits should be available.

For the MPP rays, each ray will carry an intensity weighting factor such that its contribution to the ray-field intensity at a point  $\underline{r}$  will be

$$I(\theta, \underline{r}) = \gamma(\theta, \underline{r}) \cdot I_{\text{RAY}}(\theta, \underline{r})$$

where  $I_{\text{RAY}}$  is the standard intensity and  $\gamma$  the weighting factor. For rays less than  $\theta_0$ ,  $\gamma$  will be zero until the

ray reflects from the bottom at which point it will be unity. For rays greater than  $\theta_0$ ,  $\gamma$  will be  $1 - \beta(\theta)$  until they bottom reflect at which point it will also be unity. This technique effects the desired near-field and far-field solution.

Because MPP computes the ray field in range, depth, and frequency simultaneously, only one run should be required. The ray fan spacing and the range-depth sampling mesh will be under user control with certain default conditions. The data storage and transfer are described in the next section.

## Section 3

### UNIFIED PROGRAM STRUCTURE

#### 3.1 INTRODUCTION

The advanced computational capability discussed in the preceeding sections basically requires the connection of existing acoustic models. New coding is to be kept to a minimum, mainly ensuring that the resultant structure is responsive to user needs.

#### 3.2 CONSIDERATIONS

Conceptually, the unified computational capability is quite simple: take results from program A and combine with results from program B to give final answers. In practice, however, the utility of this combined model will strongly reflect the care which goes into its design in several key areas, as discussed below.

##### 3.2.1 User-Oriented Structure

The structure must be user-oriented. Many factors are only of marginal interest to the user. For example, the job control language should be relatively simple and require minimal attention. Permanent file operations such as ATTACH and CATALOG can be performed from within Fortran control programs. Transfer of immediate information files between elements should be transparent to the user.



At the same time, it should be possible to deviate from a fixed path for special circumstances. For example, there is no need to repeat an entire sequence of calculations when only one segment is to be changed.

### 3.2.2     Input

Much of the input to the acoustic models is common to the several models: sound speed profiles, bathymetry, frequency, etc. (See Figure 8.) Other input parameters can often be omitted in favor of default values. Finally, some parameter values may be dictated or excluded by the presence of others. These considerations lead to the following:

- There should be one element of the structure that reads all input.
- Input should be checked for completeness and consistency before execution of any of the acoustic models.
- The user should be warned of possibly questionable parameter choices.
- The job should be terminated if impossible or unreasonable circumstances are present, e.g., a small job time limit or conflicting or inadequate output depth or range meshes for the wave or ray calculations.

### 3.2.3     User Conveniences

Further user protection should be supplied by the automatic cataloging of relevant intermediate results to guard against unforeseen errors such as premature

QUANTITY	CFIELD	PE	FACT	MPP
Sound velocity profiles and ranges	X	X <sup>(1)</sup>	X <sup>(2)</sup>	X <sup>(1)</sup>
SVP-specified connections	X	X <sup>(1)</sup>		X <sup>(1)</sup>
Bathymetry		X	X <sup>(2)</sup>	X
Frequencies		1	6	6
Source (starting) Depths		1	1	1
Receiver Depths		6 <sup>(3)</sup>	1	N
Maximum Range		X	X	X
Range Increment			X	X
Bottom Type			X	X
Calculation Options	X	X	X	X
Output Options	X	X	X	X

- (1) From CFIELD
- (2) Range-independent
- (3) Many for contours

Figure 8. Input Summary

time limits. This also makes it possible to repeat the problem and change only one element without rerunning everything from scratch.

### 3.3 NEW COMPONENTS

The primary computational elements for the unified structure already exist and will be discussed in the next section. Two new elements are needed to tie the structure together: a preprocessor and a postprocessor. These are discussed below (with the thoughts of Section 3.2 in mind). The overall control/information flow is shown in Figure 9.

#### 3.3.1 Preprocessor

The preprocessor will perform the following functions:

- Accept all card input to the unified calculation. A fair amount of effort is to be expended here in order to make the input processor user-oriented and intelligent. For example, if each data segment is preceded by some identification, the data segments can be arranged in an arbitrary order.
- Supply default values for unspecified parameters
- Check the input for completeness and consistency

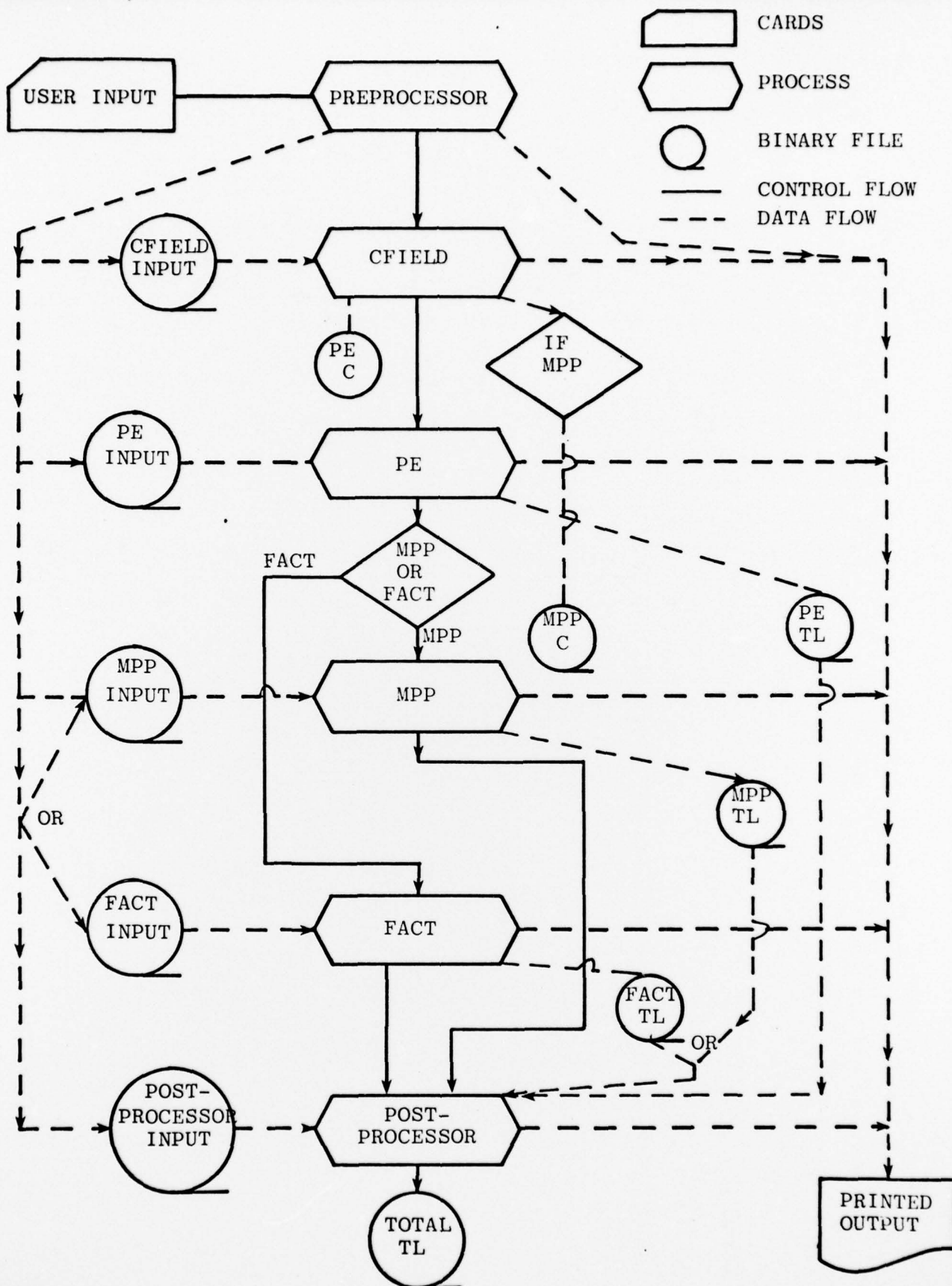


Figure 9. Control/Information Flow



- Compute physical parameters (e.g., source aperture characteristics for PE) needed by the acoustic models
- Provide a first level of protection by aborting if unreasonable circumstances are present
- Create scratch input files for all following program elements. These files will consist of environmental data, problem-specific data (frequencies, etc.) physical parameters, option flags for calculations and output and, finally, system file protocols.

### 3.3.2 Postprocessor

The postprocessor will perform the following functions:

- Accept command and option input generated by the preprocessor. Included in this data set are parameters defining the scope of the calculations (frequencies, source and receiver depths, etc.), output option flags and system file name protocols.
- Accept immediate output (transmission loss) files from the acoustic models
- Construct the final results and display according to desired options. This will include some or all of range averaging, range and/or depth mesh modification and contour plot construction operations on the model output.

## 3.4 MODIFICATIONS TO EXISTING ACOUSTIC MODELS

The unified program structure will combine selected features of a wave model (PE) and a ray model (FACT or MPP).

Since all present results of the component models will not be used and since new capabilities in each component are desired, it will be necessary to make slight modifications to the existing models. These changes fall into five categories and are discussed below.

#### 3.4.1 Cycling Capability

In order to merge results from the two types of models, it will be necessary to run each model for (possibly) a number of frequencies, source depths and/or receiver depths. At present, the models do not have this cycling capability in the needed generality. It will be necessary to add the following:

- To PE: Cycle on frequencies and/or source depths
- To FACT or MPP: Cycle on source/receiver depth pairs

#### 3.4.2 Output Quantities

In order to construct merged transmission loss contour maps, PE must save (for use by the postprocessor) a subset (generally 120 values) of the full  $2^N$  (Fourier transform) point mesh transmission-loss values at each range step.

#### 3.4.3 Computational Capability

Since the unified model is only concerned with selected features of each model, modifications must be made to isolate these features:

- PE must be modified so the user has control over the source aperture characteristics
- FACT and MPP must be modified to include contributions from bottom bounce ray paths, and to modify the ray intensities in the direct-path region.

#### 3.4.4 User Protection

In general, it may be necessary to cycle through PE and/or FACT several times in order to obtain intermediate results for the postprocessor to combine. Each of the three models will be modified to save ('CATALOG') on the system the results of each cycle. This provides protection against time limit problems and also makes it possible to re-use segments of the calculations.

#### 3.4.5 Formatting

The CFIELD code supplies sound speed profiles as a function of range to PE and the parametric description of the triangular sectors to MPP. A single version of CFIELD must be constructed to generate both output files.

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